TIME DOMAIN ELECTROMAGNETIC SURVEYS FOR ASSISTING IN DETERMINING THE GROUNDWATER RESOURCES AT THE PEARL HARBOR WELL FIELD ISLAND OF OAHU

Project Number 00159

August 2011

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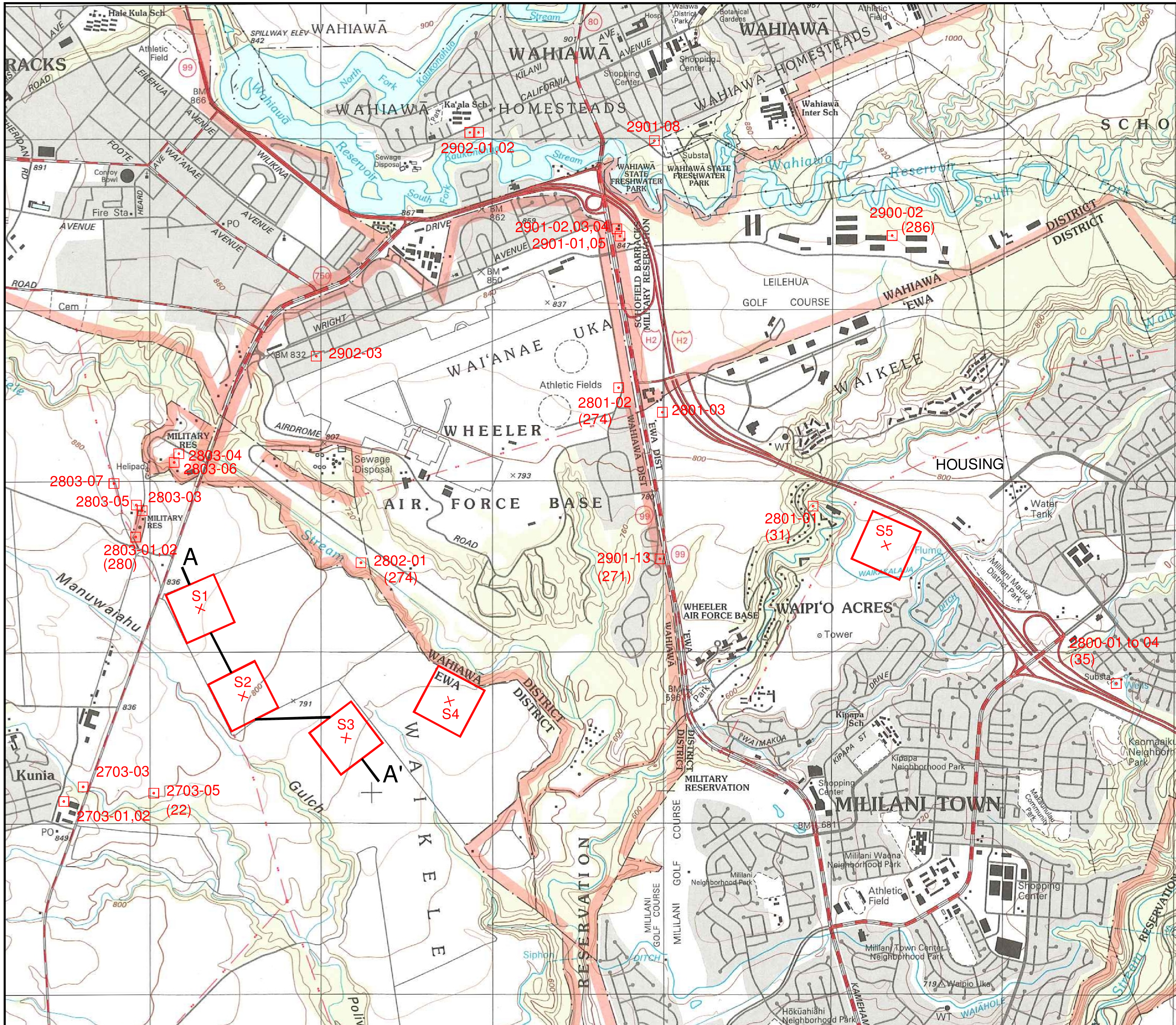
1.0 INTRODUCTION

This report contains the procedures and results of surface Time Domain Electromagnetic (TDEM) geophysical surveys performed for groundwater resource evaluation in Central Oahu near Kunia and Waipio Acres, Oahu. The property included land owned by the State of Hawaii Department of Land and Natural Resources (DLNR), Waikele Farms, Inc. (WFI) and Honbushin International Center (HIC). Zapata Incorporated (ZAPATA) performed the surveys for Belt Collins Hawaii Ltd. (BCH) and Tom Nance Water Resource Engineering (TNWRE) from July 13 through July 16, 2011.

The main objective of the TDEM surveys was to identify basal or high-level groundwater at the sounding sites to refine the boundary between the two. The surveys were conducted at five TDEM sounding sites to help determine the location for future groundwater wells. Figure 1-1 shows the locations of the TDEM soundings taken during this survey.

TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) of the subsurface. From the geoelectric section, information about geology and water quality can be inferred. This is possible because the electrical resistivity of the earth depends on lithology, porosity, degree of saturation, and concentration of dissolved solids in the groundwater. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for water well placement and well completion depths.

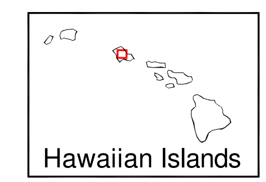


Explanation

TDEM Sounding

A-A' Section Line

2801-02 (274) Water Well, (Head in Feet)



N

0 2000 4000

Scale in Feet

Geophysical TDEM Survey
Location Map
Ewa District
Island of Oahu

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Belt Collins Hawaii Ltd.
Pearl Harbor Well Field
Central Oahu, HI

Drawn By: HJV	Checked By: RJB	Scale: 1" = 2000'	Figure: 1-1
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2.0 GEOLOGY/HYDROGEOLOGY

Groundwater resources occur on the Hawaiian Islands basically in two modes:

- In a basal mode where a lens of fresh water floats on seawater, and
- In a high-level mode where the fresh groundwater occurrence is controlled by damming structures (i.e. dikes, intrusives, etc).

Figure 2-1 illustrates the basic geologic and hydrologic framework of the Island of Oahu and the two modes of groundwater occurrences. Fresh groundwater may also occur in areas between these two modes, but production is expected to be highly variable. TDEM soundings previously taken on Hawaii have reliably mapped basal mode groundwater and the boundary between fresh water in the basal mode and high-level water occurrences.

Basal mode groundwater is shown to rest approximately at sea level near the ocean surrounding the Island of Oahu (reference Figure 2-1). This is due to the fact that the volcanic rocks, which comprise the island, allow rainfall to percolate with little impedance directly downward through the rock mass. The fresh water floats directly on seawater encroaching from the ocean. Fresh water flows laterally toward the ocean causing the fresh water lens to be thinner near the shoreline. When groundwater is under static equilibrium conditions, the Ghyben-Herzberg Principle states that for every one foot of fresh water above sea level approximately 40 feet of fresh water will exist below sea level as shown in Figure 2-2. The change from fresh water to seawater (transition zone) at depth may be relatively sharp (i.e. occurring over several tens of feet) or more gradual, depending upon hydrologic flux, horizontal and vertical permeability contrast, and other geologic factors (such as dikes). It is assumed, when resolving TDEM sounding data, that seawater saturated volcanics occur at the midpoint of the transition zone.

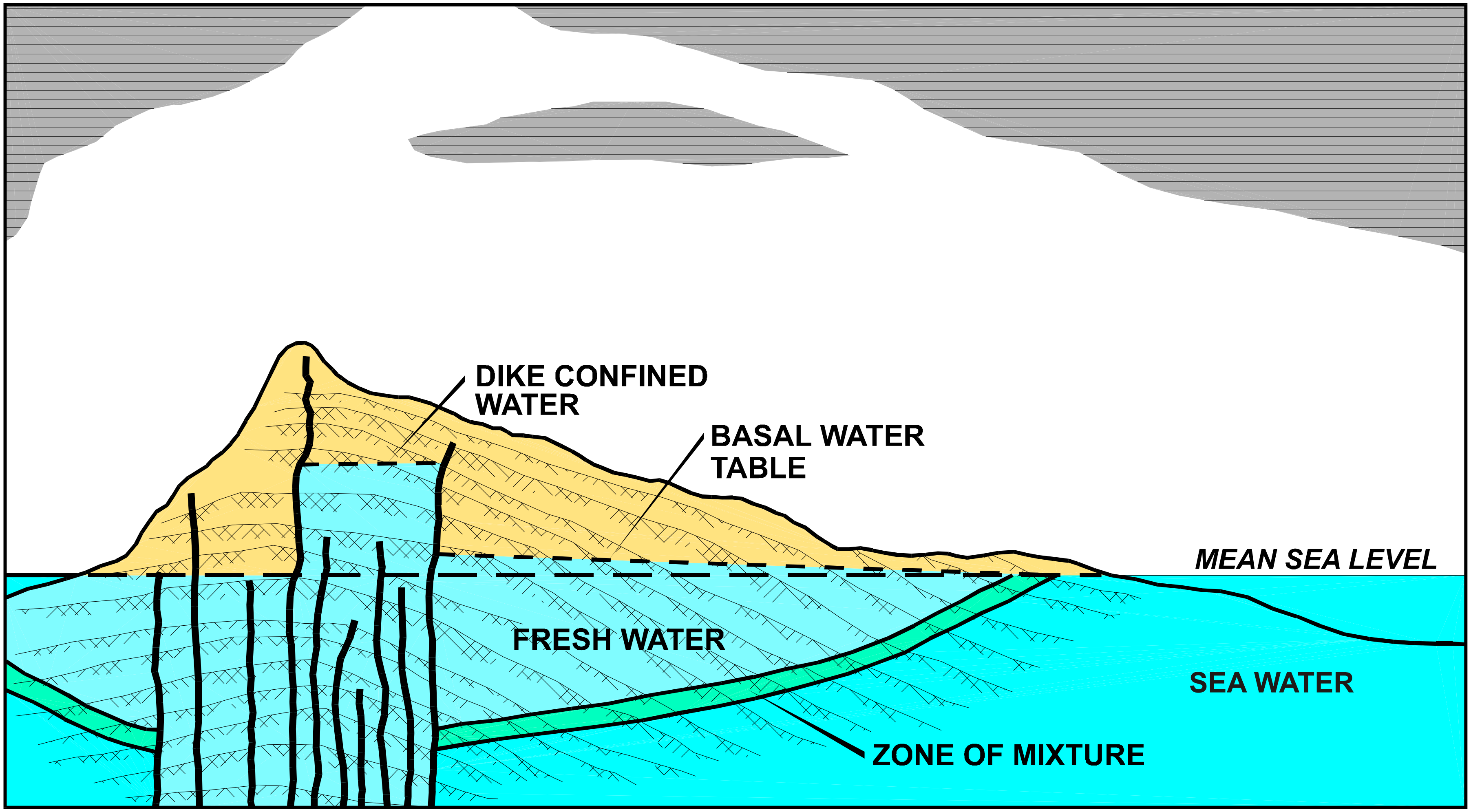
TDEM surveys are utilized to map the resistivity stratification of the subsurface. From numerous TDEM surveys on Oahu and calibration of TDEM data at groundwater wells, characteristic ranges of subsurface resistivities have been derived for the geologic/hydrologic units shown in Figure 2-3. Some overlap in resistivity values occurs between the units; however, other factors (i.e. such as ground elevation) can be used to help separate the units. Therefore, the main geologic/hydrologic units that can be derived from TDEM surveys include:

- Depth to seawater saturated volcanic rocks. This occurs in basal mode situations, and by using the Ghyben-Herzberg principle the thickness of the basal fresh water lens can be calculated.
- Weathered volcanic layers (laterite). These low to intermediate resistivity units are generally relatively thin layers (100 to 200 feet thick) that normally occur at or near the ground surface.
- Clay-poor and fresh water saturated volcanic rocks. These formations generally exhibit high resistivity values (>500 ohm-m). The extent of fresh water saturation is normally

based on geographic and elevation information, and it should be noted that fresh water layers cannot be directly detected in the TDEM data.

Groundwater damming structures (i.e. intrusives, dikes) are inferred with TDEM data by uncharacteristic sounding curves (distorted by 2-D structures), and by soundings that change between detection of seawater at depth (indicating basal mode groundwater) and soundings that map high resistivities to great depths below sea level (indicating high-level groundwater).

Figure 2-4 illustrates the combined geologic and topographic map of central Oahu showing surface deposits (QTao) and Ko'olau formation (QTkl) in the project area. There doesn’t appear to be any cinder cones, fissure vents or dikes mapped in the immediate vicinity of the TDEM soundings.



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Central Oahu, HI

Schematic Hydrogeologic Cross Section Island of Hawaii

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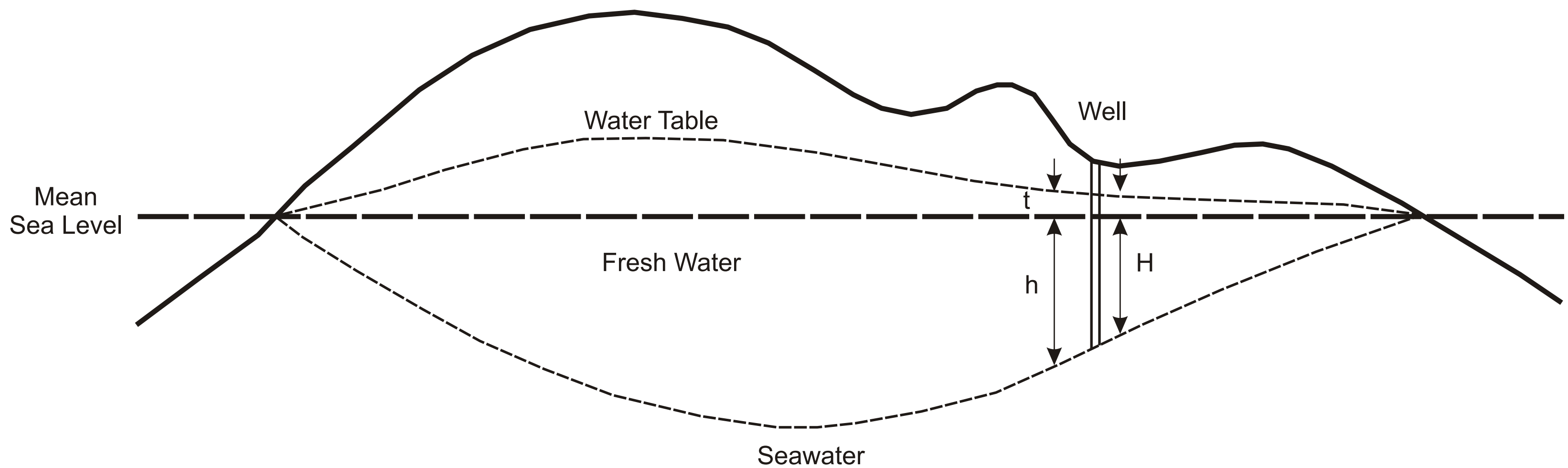
00159	August, 2011	HJV	RJB	No Scale	2-1



$$t = 1/40\ (h)$$

From: Herzberg

ZAPATA TRUST · INTEGRITY · QUALITY	**Belt Collins Hawaii Ltd.** *Pearl Harbor Well Field* *Central Oahu, HI*			**Illustration of the Ghyben-Herzberg Principle**		
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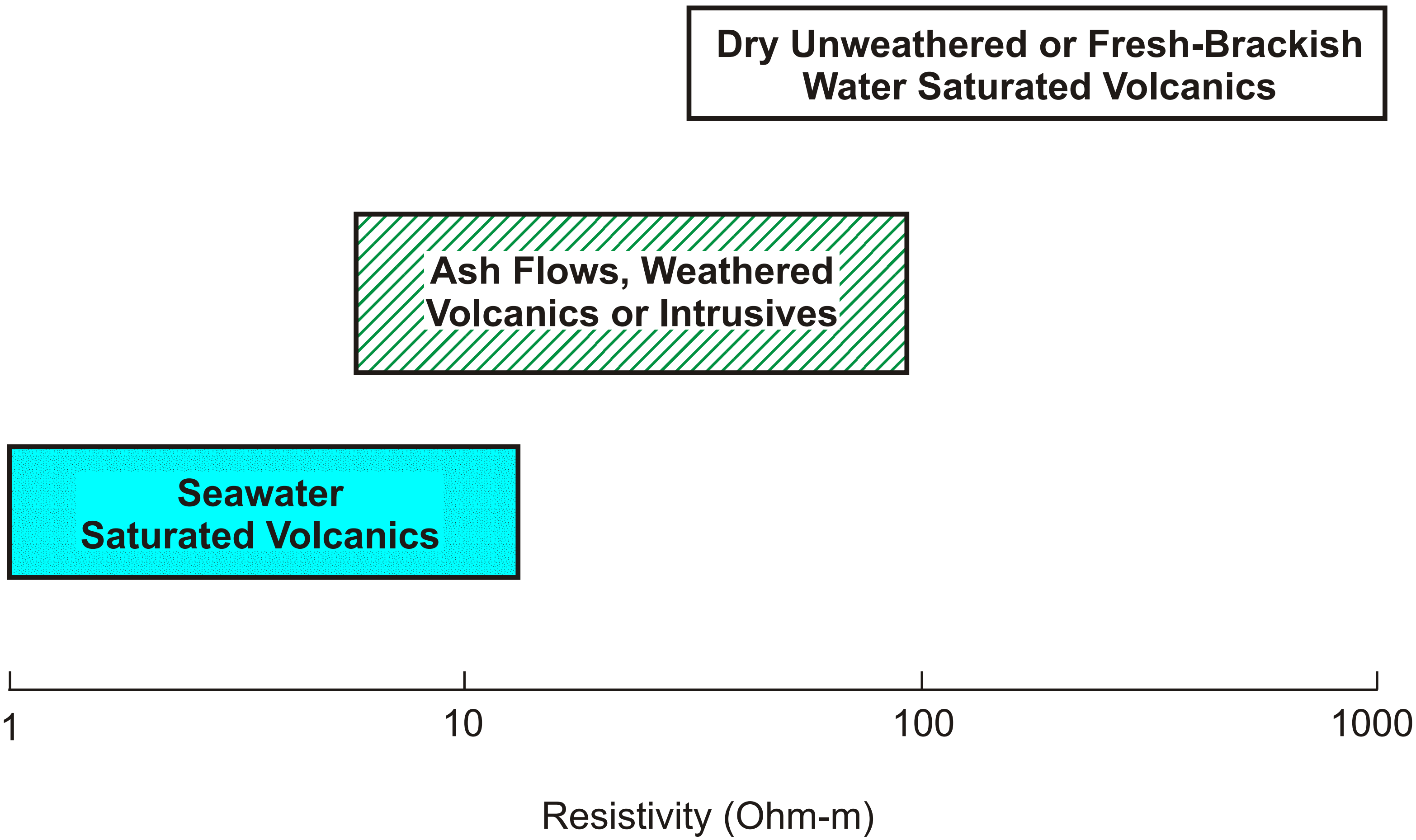

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Characteristic Resistivity Ranges
Ewa District
Island of Oahu

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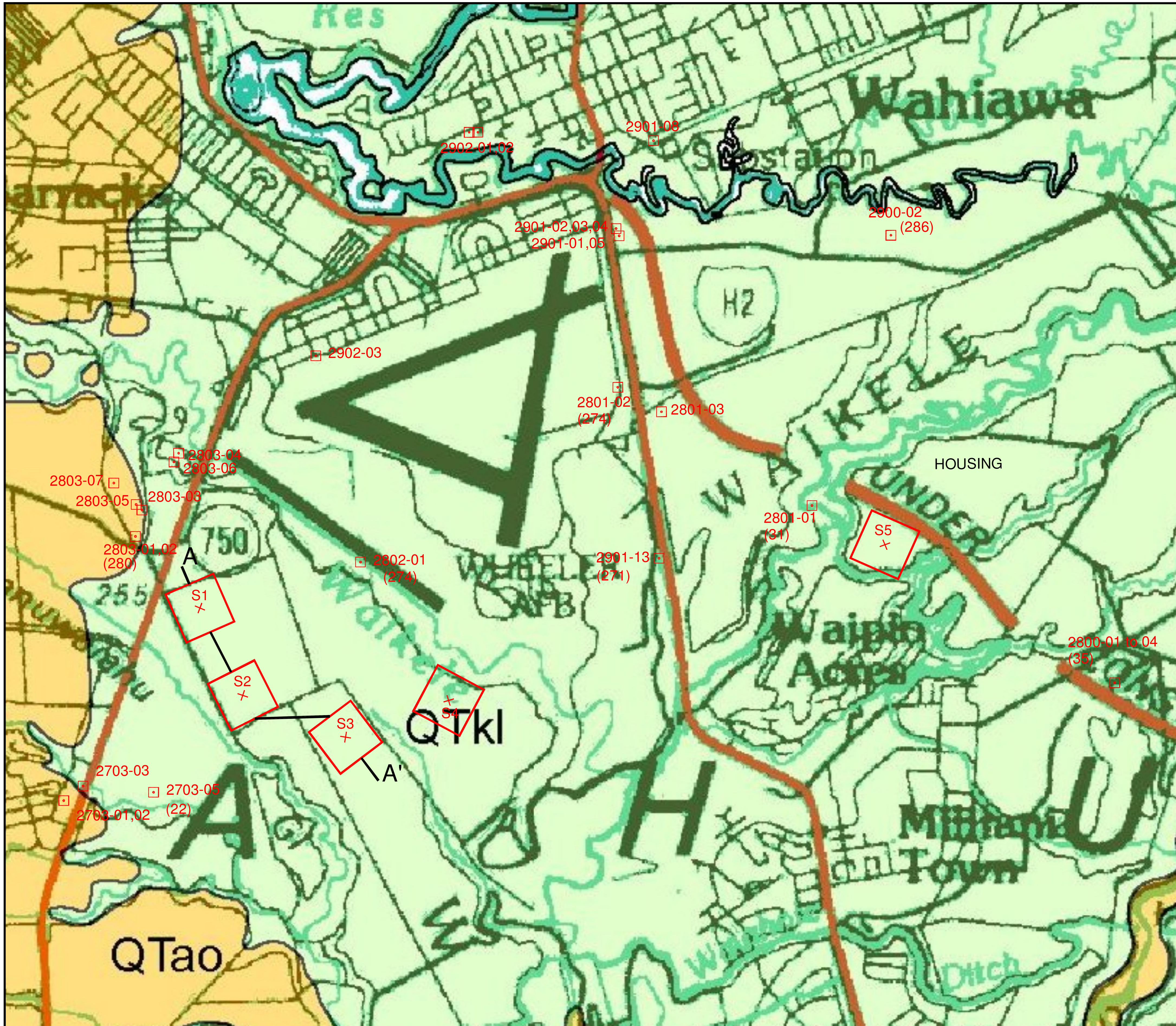
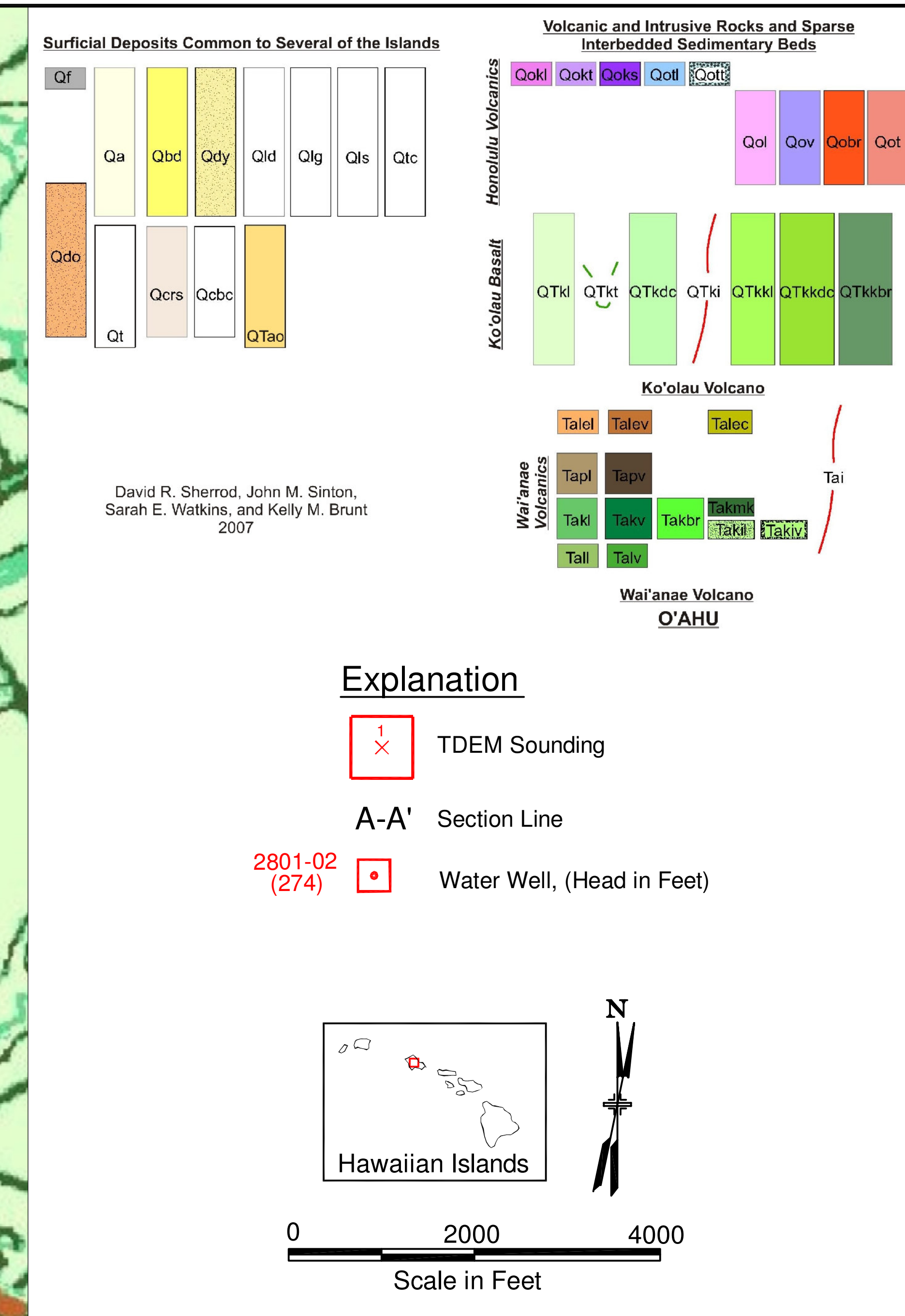
00159	August, 2011	HJV	RJB	No Scale	2-3





Geologic & Topographic Map

Ewa District
Island of Oahu

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Pearl Harbor Well Field
Central Oahu, HI

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3.0 DATA ACQUISITION AND LOGISTICS

ZAPATA mobilized a field crew consisting of a project geophysicist and geophysical technician to perform the geophysical surveys. The field crew and TDEM equipment were mobilized from Golden, Colorado to Honolulu, Hawaii. Prior to conducting the surveys, ZAPATA personnel coordinated with BCH and TNWRE personnel to determine property ownership and access. During the field work the project geophysicist coordinated with TNWRE on a daily basis to relay preliminary TDEM survey results and determine the project direction. A daily log of field activities during the TDEM surveys is presented in Table 3-1.

The Geonics EM37 geophysical system was utilized for the TDEM surveys. The EM37 system contains both a portable motor-generator powered transmitter and a PROTEM digital receiver. The main purpose of the TDEM measurements is to derive both the vertical and lateral variations in the geoelectric section (resistivity) of the subsurface. To accomplish this, TDEM soundings were collected using a central-loop array at each site. The square transmitter wire-loops were constructed using 12-gauge insulated copper wire laid on the ground surface, as illustrated in Figure 3-1. The dimensions of the transmitter wire-loops used during this survey were 1,000 by 1,000 feet for all the TDEM soundings. The EM37 transmitter was placed in each transmitter loop and square-wave current pulses were driven through the wire-loop using a current of 14 amperes. The current pulses induce eddy current flow in the subsurface of the ground. A solid-core receiver coil (1-meter diameter) attached to the PROTEM receiver was positioned in the center of each wire-loop and was used to record the decay of the secondary magnetic field from the eddy currents induced in the subsurface. The effective exploration depth of a 1,000 by 1,000-foot transmitter wire-loop array has been determined to be approximately 2,500 feet below the surface. Thus, at ground surface elevation of 1,000 feet, a search depth of approximately 1,500 feet below sea level is obtained. Greater exploration depths are reached with larger transmitter wire-loops and there are several factors that affect the depth of investigation; these include ground resistivity (in ohm-m) and surrounding ambient cultural interference (i.e. 60-cycle powerline, metal pipelines, etc). A technical note describing the principles of TDEM with case histories is given in Appendix A.

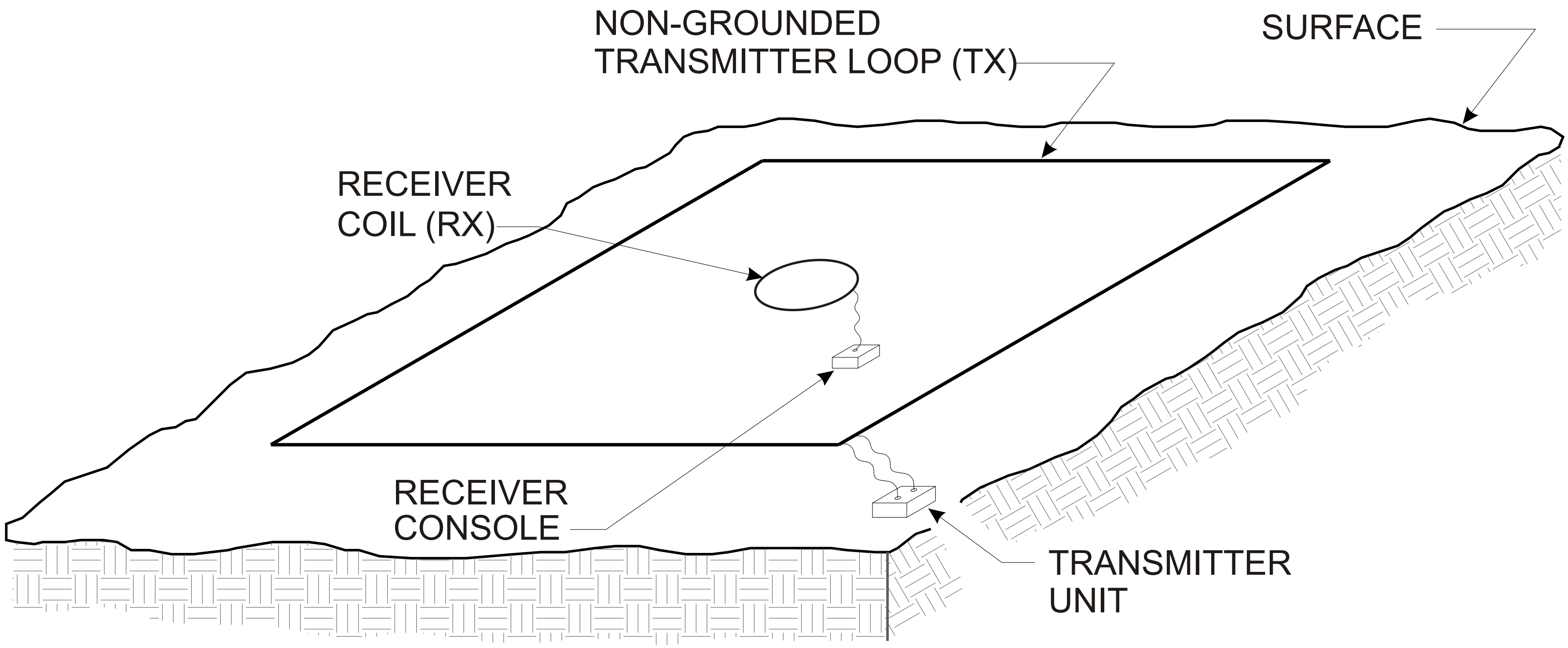
The TDEM data acquired at each sounding site consisted of measurements utilizing several receiver gain settings and two transmitter frequencies in order to obtain data over the longest possible time interval. The data were recorded using base frequencies of 3 and 30 Hz to obtain the maximum search depth for each TDEM sounding. For data quality control (QC) purposes, additional data sets were collected at a minimum of two designated locations, offset 200 feet in each direction from the center, for comparison to the central-loop data. The data from each sounding were recorded in solid-state memory in the PROTEM receiver and transferred daily to a personal computer (PC) for processing. The TDEM data collected at four of the five sites were of excellent quality. However, Sounding 4 was determined to be distorted due to a local cultural interference (i.e. metal fences or buried metal pipeline) that affected the measurement of the

TDEM data. The QC offset data sets for this sounding were also determined to be affected by the local cultural interference at this location.

The corners of the transmitter wire-loops were registered to road junctions and/or irrigation ditches located on the topographic map and existing property boundaries. In several cases, landmarks such as property gates were used to position the wire-loops on the map along with utilizing a measuring device (hip-chain) and compass to locate the loop corners. In addition, a hand-held global positioning system (GPS) with differential position accuracy of 20 feet was used to measure the center and transmitter corner of each sounding. The GPS coordinates were then used to position each loop center on a geo-referenced topographic map and the loop center elevation was subsequently derived from that position. Due mainly to overgrown fields (10-12 foot tall Guinea grass) on the DLNR property, a total of five TDEM soundings were measured during four days of fieldwork. The GPS coordinates and elevations of the TDEM transmitter loop centers and corners are given in Table 3-2 in Appendix B.

Table 3-1
Daily Log of Field Activities
Pearl Harbor Well Field, Central Oahu - TDEM Survey

Date (2011)	Activity
July 6	Ship TDEM geophysical equipment from Golden, CO to Honolulu, HI.
July 12	Mobilize ZAPATA personnel from Golden, CO to Honolulu, HI.
July 13	Unpack TDEM equipment at hotel and organize into SUV. Meet with DLNR field personnel; perform recon of access roads to Soundings 1, 2, and 4. Begin TDEM survey; lay out wire-loop and collect data on Sounding 1. Download data and perform preliminary analysis. Discuss results with TNWRE.
July 14	Lay out wire-loop and collect data on Sounding 2. Download data and perform preliminary analysis. Discuss results with TNWRE.
July 15	Lay out wire-loop and acquire data on Sounding 4. Contact Larry Jefts with WFI to discuss access to Sounding 3; register at WFI field office to gain access to Sounding 3. Lay out wire-loop and acquire data on Sounding 3. Download data and perform preliminary analysis. Discuss results with TNWRE.
July 16	Go to HIC; lay out wire-loop and acquire data on Sounding 5. Pick up wire-loop and recon access to Loops 8 and 9. Security guard said that we need to check back on Monday to get access permission. Download data and perform preliminary data analysis. Discuss results with TNWRE. Finish survey.
July 17	Day off.
July 18	Pack up TDEM equipment and deliver to FedEx at Honolulu Airport.
July 19	Mobilize ZAPATA personnel from Honolulu, HI to Kailua-Kona, HI for work on another project.



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Schematic layout of TDEM system with locations of TX and RX for Central Loop Array measurements

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00159	August, 2011	HJV	RJB	No Scale	3-1

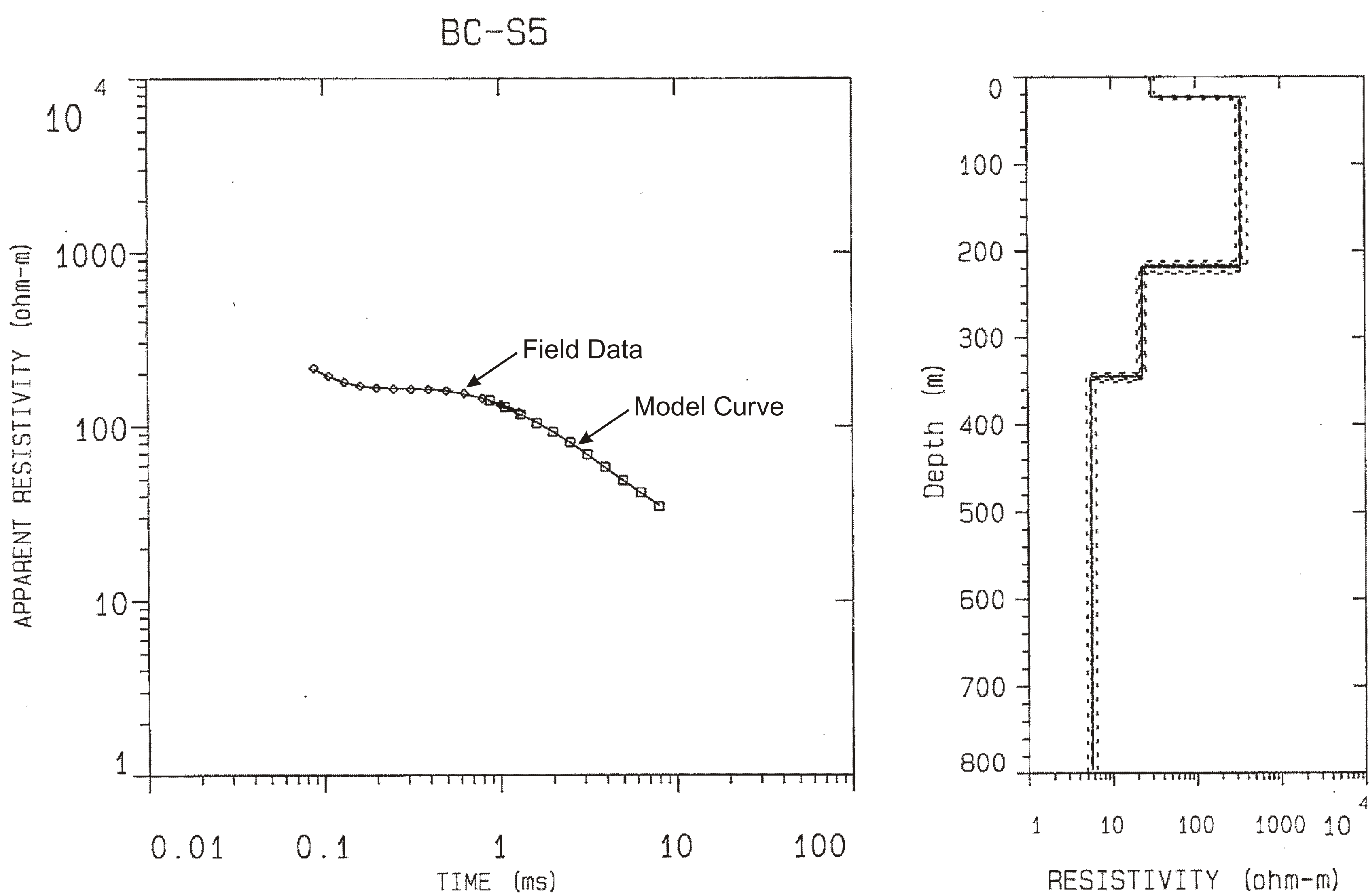
4.0 DATA PROCESSING

The geophysical field data collected for each TDEM sounding was transferred from the Geonics PROTEM ™ digital receiver to a PC for editing and processing. The processing of TDEM data begins with averaging of the electromotive forces recorded for positive and negative receiver polarities. Next, the measurements collected at two base frequencies (3 and 30 Hz) and amplifier gains are combined to give one voltage decay curve (transient). The electromotive forces collected from 20 logarithmical spaced time-channels (gates) of the decay curve are subsequently entered into the TEMIXXL™ (Interpex Ltd.) inversion program. The data are used to obtain a one-dimensional (1-D) geoelectric section that best matches the observed (field data) decay curve.

The TEMIXXL inversion program requires an initial model of the geoelectric section measured. The initial model includes the number of layers, resistivities and thickness for each of the layers. This model is usually derived from knowledge of the geologic section or from data obtained from drill holes or electric logs. The inversion program is then allowed to adjust the layer thickness and the resistivities, so that the model curve converges to best fit the field data. The inversion program does not change the total number of layers within the model curve, but allows all other parameters to change freely or they can optionally be fixed constant. To determine the influence of the number of layers on the solution, separate inversions with a different number of layers are run. Subsequently, the model with the least number of layers that best fits the field data is used.

An example of the output of the inversion program is shown on Figure 4-1 for Sounding BC-S5. This figure shows the measured data points (in terms of apparent resistivity) superimposed on a solid line on the left panel. The solid line represents the computed forward model for the geoelectric section on the right panel. This geoelectric section is the best match obtained by the inversion program. Figure 4-2 shows the tabulated inversion parameters consisting of measured data, computed data for best match solutions and an example of the table of inversion statistics. A four-layer inversion model is shown for the sounding. The model displays an upper layer with intermediate resistivity (30 ohm-m) overlying a resistive (340 ohm-m) second layer. The third layer exhibits intermediate resistivity (23 ohm-m) while the fourth layer exhibits a very low resistivity (5.6 ohm-m). The depth to the top of the fourth layer is modeled at -380 feet below sea level (bsl) in the section. The fourth layer is interpreted as volcanic units saturated with conductive seawater.

The interpreted geoelectric section derived from each TDEM sounding is not unique. The magnitude of each individual layer resistivity and thickness can normally be varied within a limited range with no significant change to the fit of the geoelectric model of the data. This variation is termed equivalence. An equivalence analysis was performed for each TDEM sounding. Both Figures 4-1 and 4-2 also show the equivalence analysis for Sounding BC-S5. This sounding is typical of the TDEM data which shows a +/-5% equivalence in depth determinations and +/-10% in individual layer resistivities. The inversion results for each sounding are given in Appendix B.



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Belt Collins Hawaii Ltd.
Pearl Harbor Well Field
Central Oahu, HI

Sounding BC-S5
Example Inversion Output
Apparent Resistivity Curve
Ewa District
Island of Oahu

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00159	August, 2011	HJV	RJB	No Scale	4-1

DATA SET: BC-S5

CLIENT: Belt Collins — DATE: 07-16-11
LOCATION: Original Sounding 10 location — SOUNDING: 5
COUNTY: Ewa District — ELEVATION: 228.60 m
PROJECT: Pearl Harbor Well Field — EQUIPMENT: Geonics PROTEM
LOOP SIZE: 305.000 m by 305.000 m — AZIMUTH:
COIL LOC: 0.000 m (X), 0.000 m (Y) — TIME CONSTANT: NONE
SOUNDING COORDINATES: E: 10.0000 N: 1.0000 SLOPE: NONE

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 1.269 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(ft)	CONDUCTANCE (Siemens)
			228.6	750.0	
1	29.84	23.19	205.4	672.5	0.777
2	339.8	194.4	10.97	36.0	0.572
3	22.99	126.9	-115.9	-380.6	5.52
4	5.61				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	28.706	29.849	32.970
	2	300.939	339.884	407.866
	3	19.715	22.991	25.475
	4	4.934	5.611	6.426
THICK	1	22.225	23.194	26.522
	2	188.001	194.432	202.490
	3	122.178	126.915	131.368
DEPTH	1	22.225	23.194	26.522
	2	211.371	217.626	225.959
	3	340.657	344.540	350.663

Equivalence Analysis

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	536.6	550.4	-2.56
2	1.06	377.2	382.6	-1.43
3	1.31	261.4	261.9	-0.191
4	1.61	183.5	181.8	0.928
5	2.00	128.0	127.8	0.145
6	2.50	90.65	90.75	-0.115
7	3.14	64.98	65.23	-0.385
8	3.95	46.73	47.30	-1.20
9	4.99	33.70	33.80	-0.301
10	6.31	23.93	24.21	-1.17
11	7.99	17.41	17.01	2.27

CURRENT: 14.00 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 30.00 Hz GAIN: 4 RAMP TIME: 150.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
12	0.0881	89129.1	90586.9	-1.63
13	0.106	64459.1	65005.3	-0.847
14	0.131	43430.3	43603.3	-0.398
15	0.161	27665.4	27722.8	-0.207
16	0.200	16871.7	16844.6	0.160
17	0.250	9879.8	9786.4	0.945
18	0.314	5637.3	5555.1	1.45
19	0.395	3197.8	3180.5	0.541
20	0.499	1828.4	1820.4	0.437
21	0.631	1072.0	1092.2	-1.88
22	0.799	654.5	654.7	-0.0342
23	1.01	411.6	405.7	1.43
24	1.28	264.1	256.9	2.74

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.66						
P 2	0.06	0.08					
P 3	0.03	-0.01	0.16				
P 4	-0.02	0.00	-0.08	0.12			
T 1	-0.37	-0.13	0.06	-0.02	0.50		
T 2	0.02	0.08	0.22	-0.04	0.02	0.90	
T 3	0.04	-0.10	-0.10	0.12	0.06	0.06	0.66

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Sounding BC-S5
Example of Tabulated Data From Inversion
Ewa District
Island of Oahu

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
00159	August, 2011	HJV	RJB	No Scale	4-2

5.0 INTERPRETATION AND RESULTS

5.1 TDEM SOUNDING DATA

From each TDEM sounding, the geoelectric section of the subsurface is derived. The results of the one-dimensional (1-D) inversion from the individual TDEM soundings can be linked together, as layers with similar resistivities, to create a 2-D geoelectric cross-section along a survey line. A total of five TDEM soundings were collected on the DNLR, WFI and HIC properties during this project (reference Figure 1-1). From the TDEM surveys one geoelectric cross-section was generated. The correlation between the geoelectric layers and lithologic units, illustrated on Figure 2-3, were used to interpret the geoelectric cross-section. Sounding BC-S4 was not used in the interpretation because it was determined to be affected by local cultural interference (e.g. buried pipe line, etc.).

5.2 GEOELECTRIC CROSS-SECTION – LINE 1 (A-A')

Figure 5-1 shows the layered geoelectric cross-section interpreted from TDEM data collected along Line 1. The soundings are located along the north side of Manuwaiahu Gulch in a roughly northwest to southeast direction. Soundings 1 and 2 were located along a dirt road in overgrown pineapple fields while Sounding 3 was positioned in a cultivated farm field.

In the geoelectric cross-section a four-layer model is interpreted for Sounding BC-S1. The top layer exhibits an intermediate resistivity (43 ohm-m) that is interpreted as weathered surface laterite with a thickness of 230 feet. The second layer displays a high resistivity of 256 ohm-m, which is interpreted as dry, clay-poor volcanic formations located both above and below sea level in the section. The thickness of the second layer is interpreted to be 605 feet. The third layer exhibits intermediate resistivity (28 ohm-m) occurring at a depth of 15 feet below sea level (bsl) and is interpreted to represent weathered volcanic layers at depth beneath this sounding. The fourth layer shows low resistivity (9 ohm-m) to the approximate maximum depth of exploration (~1,500 feet bsl). The third and fourth layer resistivities are interpreted to be the result of 1) distortion of the data by 2-D geologic structures (e.g. dikes), 2) the presence of significant amounts of fine-grained materials (clays) in this area, or 3) saturation of this portion of the section with brackish groundwater. Well 2803-01 is located approximately 1,800 feet northwest of BC-S1 and is reported to contain high level groundwater with static water level (head) of 280 feet (per com T. Nance). It is possible that a subsurface geologic feature is causing non-layered earth conditions (e.g. 2-D dike, intrusive) that act as possible groundwater damming structure beneath this area of the site. There are, however, no surface geologic features (i.e. cones, vents, etc.) shown in the immediate vicinity of this sounding to confirm these subsurface conditions.

A three-layer section is interpreted for both Soundings BC-S2 and BC-S3. The upper layer exhibits intermediate resistivity ranging from 40 to 44 ohm-m and is interpreted as weathered surface laterite with a thickness of 200 feet in these areas of the property. The second and third layers in this portion of the section show high resistivities that range from 663 to > 1,000 ohm-m.

These layers are interpreted as dry, clay-poor volcanic formations located both above and below sea level. Where the third layer occurs below sea level it is expected to be saturated with fresh-brackish basal mode groundwater at depth beneath the soundings. Therefore, Soundings BC-S2 and S3 are interpreted to be located above a groundwater damming structure (e.g. dike, intrusive) in this area of the property and the potential for high-level groundwater may exist beneath these soundings. The exact location of the groundwater barrier is not known (due to the limited TDEM data in this area), but is expected to be located south of Sounding BC-S3.

5.3 HYDROGEOLOGIC INTERPRETATIONS

Table 5-1 contains the approximate thickness of the fresh-brackish water lens calculated from the elevation of the seawater interface interpreted from the TDEM soundings taken at the various property locations. The table includes the value of static water level (head) calculated by using the Gheyben-Herzberg Principle.

Table 5-1
Hydrogeologic Information Derived From TDEM Soundings
PEARL HARBOR WELL FIELD, CENTRAL OAHU
(Values in Feet)

Sounding Number	Surface Elevation	Elevation of Top of the Conductive Layer	Calculated Static Water Level (Head) Using Ghyben-Herzberg Principle	Approximate Thickness of Fresh-Brackish Water Lens
BC-S1	820	*	*	*
BC-S2	800	*	*	*
BC-S3	765	*	*	*
BC-S4	755	**	**	**
BC-S5	750	-380	9.5	389

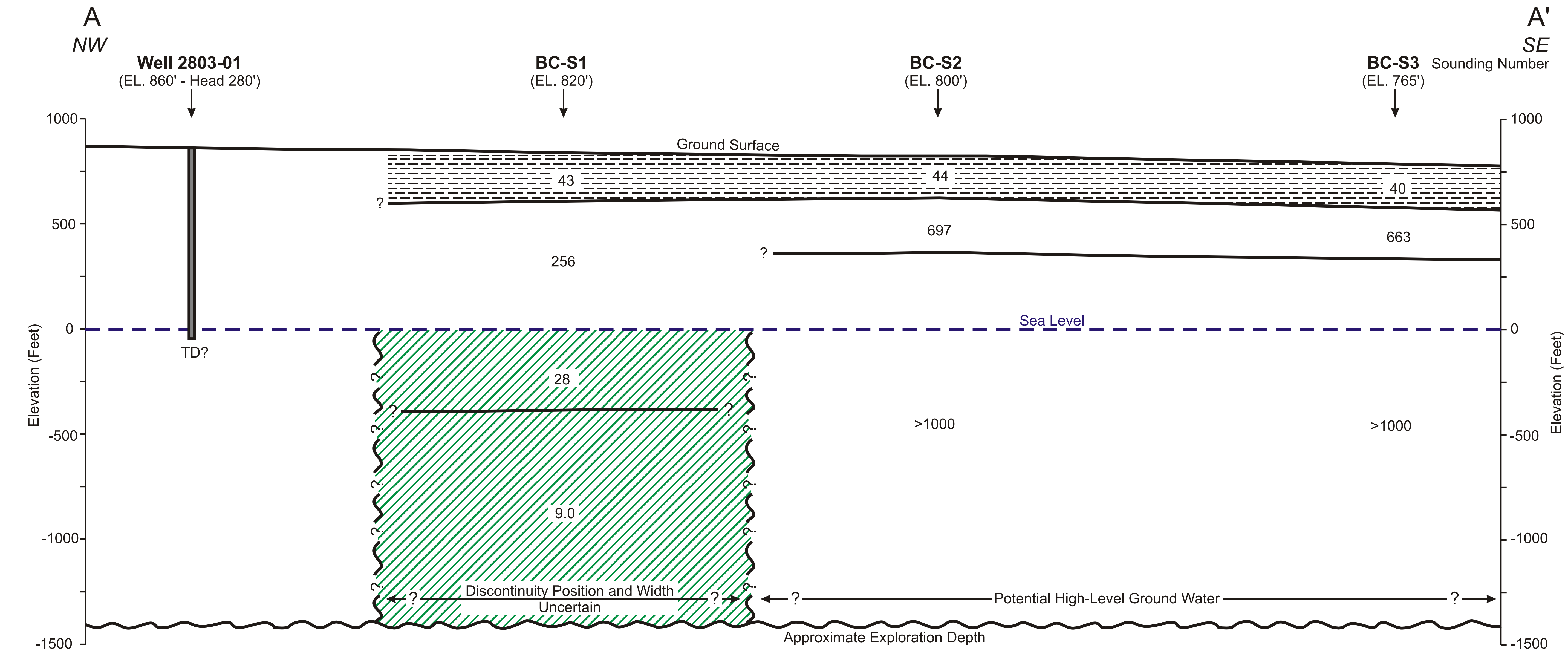
*Sounding where seawater was not detected.
**Sounding that was distorted by local cultural interference (e.g. buried pipeline, etc.).

The TDEM data is further summarized on the interpretation map shown in Figure 5-2. On this map the soundings are color coded as follows:

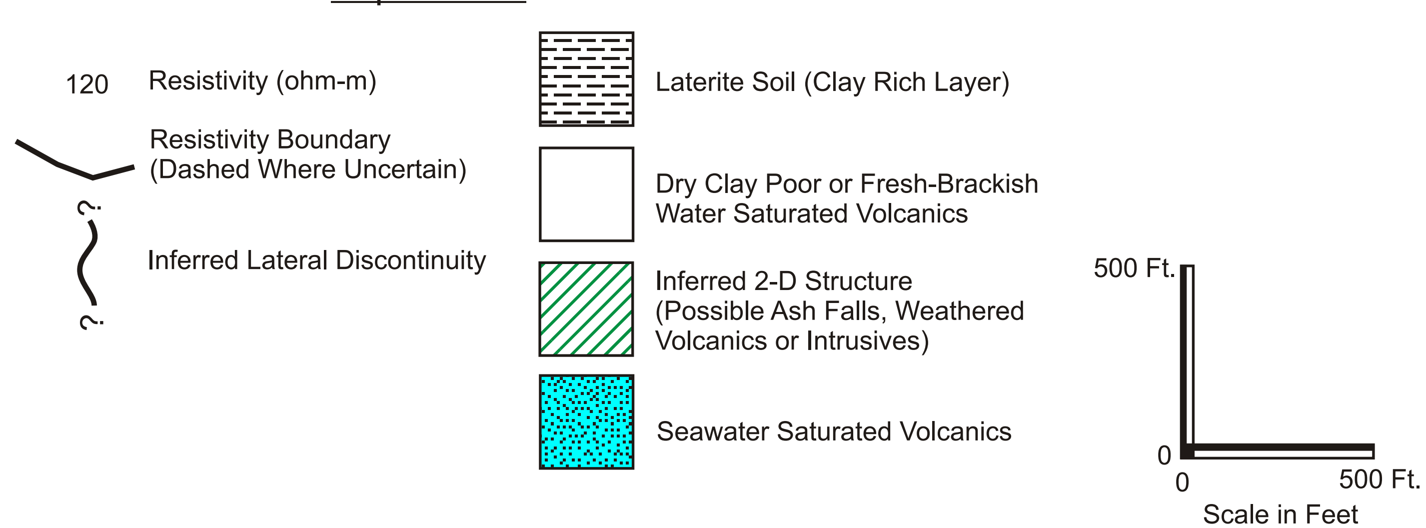
- Blue – colored soundings detected seawater at depth. The depth to the seawater interface is given (e.g. -380 feet).
- Green – colored soundings are interpreted to be located within areas that have detected intermediate resistivity in which 2-D structures (e.g. dikes, ash flows, etc) have likely distorted the true resistivity values.

- Yellow – colored soundings are located in areas that have potential for high-level groundwater.

On this map S5 exhibits a low resistivity (5 ohm-m) layer that was detected below sea level. A fresh-brackish water lens is interpreted to occur in the basal mode beneath this sounding and it is expected to be 380 feet thick (head of 9.5 feet). The accuracy of determining the depth to the seawater interface from TDEM soundings is estimated to be +/-5% of the total depth calculated in the sounding, (e.g. from the ground surface to the seawater interface).



Explanation



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Belt Collins Hawaii Ltd.
Pearl Harbor Well Field
Central Oahu, HI

Geoelectric Cross-Section from 1-D TDEM Inversions Line 1 A-A'
Ewa District,
Island of Oahu, Hawaii

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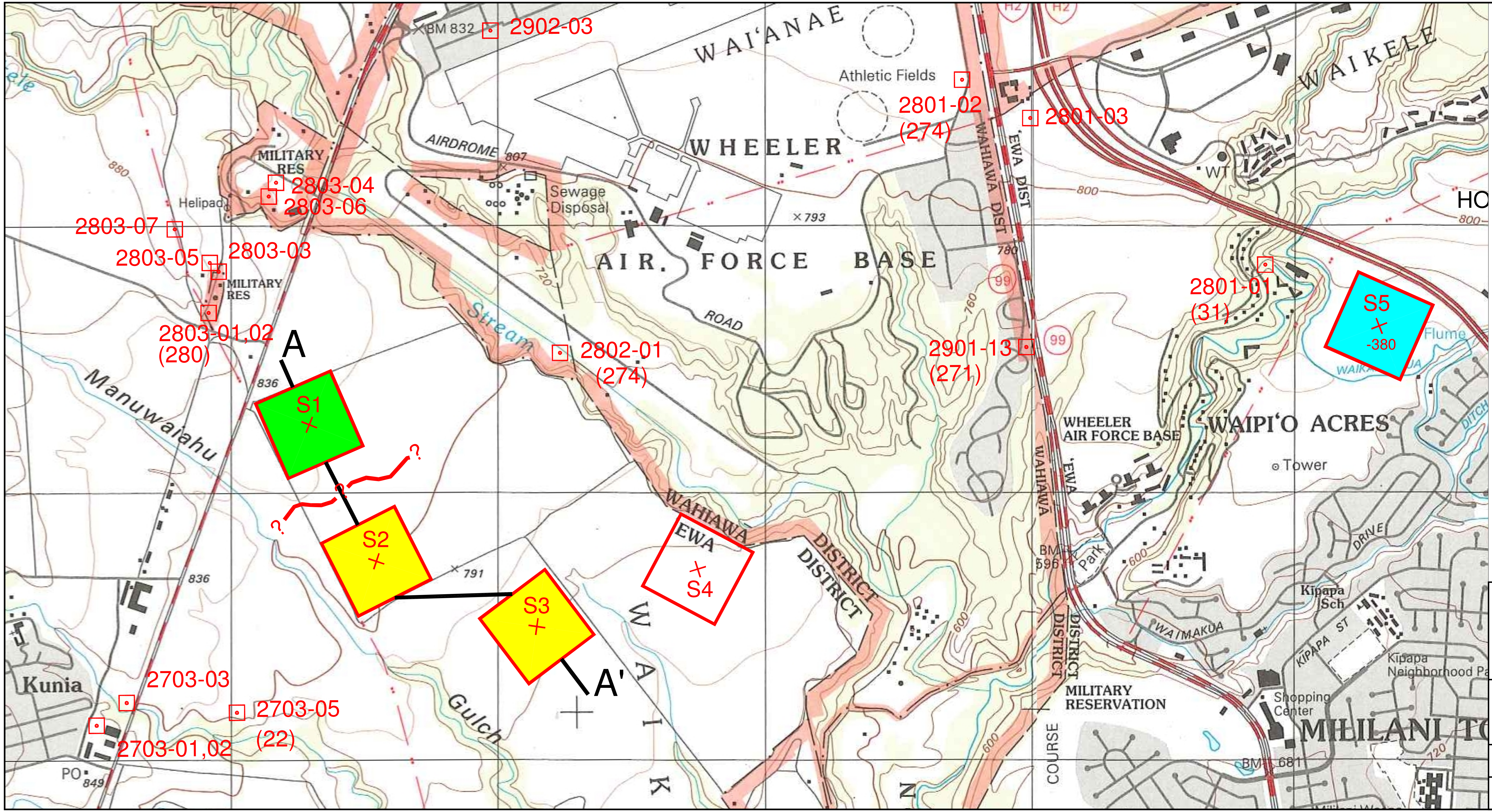
Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
00159	August, 2011	HJV	RJB	As Shown	5-1

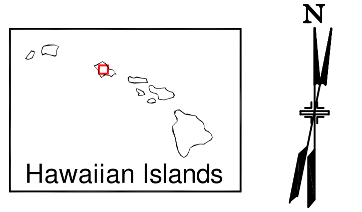


Explanation

☒	TDEM Sounding
A-A'	Section Line
2801-02 (274) ⊡	Water Well, (Head in Feet)

Explanation

-380	Approximate Elevation of Top of Salt Water Interface in Feet
(cyan)	Sounding in which Groundwater is expected in basal mode
(green)	Sounding Interpreted to be located within Groundwater Barrier (Zone of Change) Data may be distorted by 2-D Geologic Structures
(yellow)	Sounding in which Groundwater is expected to be controlled by Geologic Structure (Potential High-Level Water)
?~?	Inferred Geologic/Hydrologic Discontinuity (Position and Width Uncertain)



0 1000 2000
Scale in Feet

Geophysical TDEM Survey
Summary Interpretation Map
Ewa District
Island of Oahu

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Belt Collins Hawaii Ltd.
Pearl Harbor Well Field
Central Oahu, HI

Drawn By: HJV	Checked By: RJB	Scale: 1" = 1000'	Figure: 5-2
301 Commercial Road, Suite B, Golden, Colorado 80401	Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Date: August, 2011	Project No: 00159

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM surveys was to identify basal or high-level groundwater resources at sounding sites to refine the boundary between the two in areas between the towns of Kunia and Waipio Acres in Central Oahu. The optimum locations for basal mode groundwater are expected to occur where the thickest lens of fresh-brackish water is detected floating on seawater. The optimum locations for high-level groundwater are expected to occur above groundwater damming structures (e.g. dikes, etc.).

The results from the TDEM surveys are shown on Figures 5-1, 5-2 and in Table 5-1. Well 2803-01 has a reported head of 280 feet and is located approximately 1,800 feet northwest of Sounding BC-S1, and this data shows an intermediate resistivity (28 ohm-m) layer occurring at a depth of 15 feet bsl. From the TDEM data, a geologic/hydrologic discontinuity (e.g. 2-D dike structure) is interpreted at depth beneath this sounding, which is possibly causing damming of groundwater in this area. The potential for high-level groundwater appears to exist beneath S2 and S3, where high resistivity layers (>1,000 ohm-m) are interpreted to the maximum search depth of these soundings (about 1,500 ft bsl).

Sounding BC-S5 detected a seawater interface at depth and therefore a direct comparison of head can be made with a well near this site. The interpreted thickness of the fresh-brackish water lens is estimated to be 380 feet thick (9.5 feet head) beneath Sounding S5. Well 2801-01 has a reported head of 31 feet and is located in the gulch approximately 1,500 feet west of BC-S5. The difference in head calculated at Sounding BC-S5 (9.5 feet) and Well 2801-01 (31 feet) is significant and the reason for it is not known. However, this sounding may be located on or near a vertical 2-D geologic structure (e.g. dike, intrusive), which is likely causing distortion of the sounding data in this area.

Because of the limited TDEM data at the project site, additional TDEM soundings located both south of Sounding BC-S3 and west of Sounding BC-S5 will help to define the extent of potential basal and high-level groundwater resources in these areas of the property.

7.0 CERTIFICATION AND DISCLAIMER

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Zapata Incorporated Senior Geophysicists.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

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